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The CELSS Breadboard Project at Kennedy Space Center is charged with demonstrating the feasibility of bioregenerative life support systems on a one-person scale. The Biomass Production Chamber (BPC), a 113 $m^3$ pre-prototype closed chamber, is the primary facility for large scale evaluation of bioregenerative life support systems.

The components and design characteristics of the BPC have been fully described in previous publications (Prince et al., 1987). Control of environmental growing conditions and monitoring the physiological responses of the crops will be key components of an operational CELSS in order to successfully grow a crop. Wheat, soybean, potato and lettuce have been successfully grown in the BPC.

In addition to the primary regulatory role of the monitoring and control system, the data obtained are a useful resource for plant physiologists, system analysists, and crop modelers. Redundancy in both monitoring and control sensors provide a data set for evaluating active control systems, fuzzy logic, physiological models and systems efficiency. The data being obtained by the KSC Breadboard project are being used by researchers in government, academia, and private industry as a test set for a variety of projects (Drysdale, et al., 1992; Volk et al., 1993).

The modelling efforts have identified a need for data review prior to releasing it to modelling groups. Of special interest is a need to identify and remove data points that do not accurately reflect either the environment or the physiological response of the crop. Aberrant data points can originate from a number of sources, including sensor drift, sensor failure, control over-rides, hardware failure, calibration errors and human input error on manually obtained data.

In response to these needs, a quality assurance protocol was implemented in 1993 with the planting of experiment BWT931: Wheat cv. Yecora Rojo. A discussion of the protocol, description of the parameters, and policies for database access are described below.

## DATA VALIDATION PROTOCOL:

*Data acquisition:* The BPC was modified in 1992 to create two chambers for performing experimental work. Each compartment of the BPC has independent monitoring and control systems. Sensors connected to a programmable logic controller (PLC) are used to maintain environmental set points. An independent monitoring system (MS), with a different set of sensors, records actual environmental conditions at specific sites within the chamber (Fortson, et al., 1992). The impact of that modification on key environmental parameters within the chambers has been documented (Stutte, et al. 1993). The conclusion of that report was that there were no physiologically detrimental effects of the monitoring and control attributable to the control system.

Both the PLC and MS sensor data of actively controlled parameters are collected in 5-minute intervals and stored on an HP-9000 minicomputer. This provided redundant data set of multiple parameters that is temporally synchronized wth a duplicate set of sensors. Non-controlled parameters (e.g., flow of liquid and gas) are monitored with a single set of sensors through the MS and compared with manually obtained readings.

Sensor maintenance and calibration are ongoing operations during a growout. The amount of time spent in sensor calibration and replacement is dependent upon the sensor type (Fortson, et al., 1992). In addition to environmental conditions, the opening and closing of solenoids and valves are also monitored and stored, as well as the alarm and alert set points of each parameter.

In all, a total of 68 parameters are currently being monitored. Seventeen parameters were identified as candidates for inclusion in the initial KSC validated data set.

**PARAMETERS:**

The following parameters were identified for inclusion in the KSC validated database because of the perceived significance of these parameters in regulating plant growth and development and in monitoring of the CELSS bioregenerative life support functions: water purification, $CO_2$ scrubbing, $O_2$ production, and biomass production.

*Relative Humidity* (RH): PLC relative humidity values are obtained with General Eastern[1] sensors located in the air handling system prior to entry into the chamber (2 sensors). MS values are obtained with Vaisala sensors at tray level within the chamber (4 sensors). The MS data are considered default values.

*Air Temperature* (TC): PLC air temperature values are obtained with General Eastern sensors located in the air handling system prior to entry into the chamber (2 sensors). MS values are obtained with coated type J thermocouples at tray level within the chamber (4 sensors). The MS data are considered default values.

*Differential Pressure* (PR): PLC air pressures are obtained with 0-4.82 kPa pressure transducers (Teledyne Taber) placed in the chamber (2 sensors). MS values are obtained with 0-2.06 kPa pressure transducers placed in the chamber (2 sensors). The MS data are considered default values.

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[1] Mention of a tradename does not constitute an endorsement by either the National Aeronatics and Space Administration or The Bionetics Corportion.

*pH* (PH): PLC pH readings are obtained with Signet pH sensors placed in the nutrient delivery system input line (4 sensors). MS readings are obtained with Omega pH electrodes placed in the nutrient delivery system return line (4 sensors). PLC data are considered default values.

*Electrical conductivity* (CD): PLC conductivity readings are obtained with Signet conductivity sensors placed in the nutrient delivery system input line (4 sensors). MS readings are repeated from the Omega EC sensors. PLC data are considered default values.

*Nutrient Temperature* (NT): PLC nutrient delivery system temperatures are obtained with Signet temperature sensors placed in the nutrient delivery system input line (4 sensors). MS readings are obtained with type J thermocouples placed in the nutrient delivery system return line (4 sensors). PLC data are considered default values.

*Photosynthetic Photon Flux* (QM): No PLC values are obtained. MS readings are obtained from Licor Quantum sensors (400-700 nm) placed at the plant canopy under each controllable light bank (8 sensors). The PPF sensors are not mobile, so are used to indicate photoperiods only. Canopy level PPF values are obtained with a Licor Quantum sensor at weekly readings and a linear regression model used to calculate default PPF values.

*Carbon Dioxide Concentration* (C2): PLC values are obtained from an Anarad Model AR-203 infrared gas analyzer (2 sensors). MS values are obtained from an Licor Model 6262 Infrared Gas Analyzer which cycles between the upper and lower chambers (1 sensor, 2 values). The MS data are considered default values.

*Oxygen Concentration* (O2): PLC values are obtained with an Anared Model 202 fuel cell detector (2 sensors). MS values are obtained from and Amatek Model S-3A stabilized zirconia detector which cycles between the upper and lower chambers (1 sensor, 2 values). The MS data are considered default values.

*Flow of Carbon Dioxide* (MF): No PLC values are obtained. MS readings of the liters of carbon dioxide required to maintain a setpoint in each chamber are obtained from Brooks 5860 mass flow sensors (2 sensors).

*Flow of Oxygen* (FO): No PLC values are obtained. MS readings of the liters of O2 removed from the chamber with Allied healthcare oxygen concentrators are obtained from Brooks 5860 mass flow sensors (2 sensors).

*Flow of Condensate to Collection Tank* (FD): No PLC values are obtained. MS readings of liters of condensate collected from each chamber are recorded with mass flow sensors (2 readings).

*Flow of Condensate to Stock Solutions* (FS): No PLC values are obtained. MS readings of liters of condensate collected for use in making stock solutions are recorded with inline Headland IR-opflow mass flow sensors (2 sensors).

*Flow of Condensate to Humidity Control* (FH): No PLC values are obtained. MS readings of ml of condensate used to maintain relative humidity setpoints are recorded with inline Headland IR-opflow mass flow sensors (2 sensors).

*Flow of Condensate to Drain* (FF): No PLC values are obtained. MS readings of liters of condensate drained from the condensate collection system are recorded with inline Headland IR-opflow mass flow sensors (2 sensors).

*Flow of Condensate to NDS* (FT): No PLC values are obtained. MS readings of liters of collected condensate used to replace water used from the NDS are recorded with inline Headland IR-opflow mass flow sensors (4 sensors).

*Flow of pH stock solution* (FP): No PLC values are obtained. MS readings of ml of acid required to maintain a pH setpoint are recorded with inline Headland IR-opflow mass flow sensors (4 sensors).

*Flow of conductivity stock solution* (FC): No PLC values are obtained. MS readings of ml of nutrient stock solution required to maintain an EC setpoint are recorded with inline Headland IR-opflow mass flow sensors (4 sensors).

A total of 288 data points per day are collected and stored from each sensor. The monitoring and control system produces 16,128 data points per day from the MS and 6,336 data points per day from the PLC, for a total of 22,464 data points per day. The validation processes result in 14,976 data points per day. The protocol used for validation is described below.

## PROTOCOL FOR DATABASE VALIDATION

An ASCII dataset which combines the MS and PLC data is produced weekly from the 5-minute data stored on a Hewlett Packard-9000. The combined dataset is referenced to date, to day after planting and to collection time.

The ASCII data set is converted to Quattro Pro format and manually scanned for aberrant data by designated personnel. A subjective decision is made either to accept the default sensor value, replace the default value with the backup sensor value, modify the values (e.g., calibration offset), or delete the values entirely from the data set for each data point. A written record of those decisions is maintained.

The validated weekly data are then saved in ASCII format for retrieval and inclusion in the validated dataset. The minimum and maximum values for each week are obtained in order to identify out-of-range values as an added level of quality assurance. The validated data set is then made available to authorized users.

**The overriding principle is to describe the actual conditions the crops experienced and the physiological response to those conditions as accurately as possible.**

In most cases, the default values are accepted and the backup values are discarded. However, there are instances when the database was modified based on the subjective evaluation of the data reviewers. The procedures used can best be described with some examples.

*EXAMPLE 1:* Both the MS and PLC values for air temperature are within 0.5 C of each other. ACTION: The MS values are accepted since they are the default values.

*EXAMPLE 2:* MS values for pH remain relatively constant on all levels for 72 hours, but PLC values for level 4 are drifting upward during the time period. Recalibration indicates that sensor drift has occurred. ACTION: Accept PLC values for levels 1,2 and 3 and MS values for level 4 since calibration was incorrect on primary sensor.

*EXAMPLE 3:* Mass flow of $CO_2$ into the chamber was increasing, then resets in the middle of the day to 0 because of an intermittent power failure. ACTION: Modify the dataset by adding an offset to values collected after restoring the collection system.

*EXAMPLE 4:* Flow of gas from the oxygen concentrator control is found to be inaccurate because of a leak in the air line. There are no backup sensors. ACTION: If the offset is a constant, then modify the data. If the offset is not a constant, delete the data.

*EXAMPLE 5:* PLC and MS are taken offline for 30 minutes in order for software modifications to be made. No data are collected: ACTION: Replace missing data with appropriate data.

During BWT931, the first implementation of the validation protocol, it was found that calibration errors, and or sensor failures resulted in data which correctly reflected overall trends in crop responses, but lacked the accuracy necessary for system modelling. As a consequence, those values have not been included in the dataset, although the parameter has been listed. A missing value is entered as "~". Although the data are not available for BWT931, they will become available for subsequent BPC growouts.

## DATABASE ACCESS:

High quality data sets which integrate environmental and physiological responses of a plant population throughout its life cycle are not readily available to plant physiologists, crop modelers or systems analysts. The KSC validated dataset is being developed in order to facilitate the development of crop development models, to test monitoring and control strategies, and to identify limitations in crop production systems. While these environmental conditions selected during a growout are designed to evaluate conditions suitable for a CELSS, it is believed that the data also have value to the broader plant scientist and system engineering communities as well.

The KSC database is available to the scientific research community in the following formats:

*KSC VALIDATED DATABASE SUBSET:*

A one-week subset of the KSC validated data set (2016 data lines) in ASCII is available upon request. This data option allows the development and testing of digital filtering functions, fuzzy logic programs, and development models. It is believed that this test-set will be of greatest value to the engineering community during system development and design.

*KSC VALIDATED DATABASE SUMMARY:*

Daily averages of the environmental conditions and physiological responses for each parameter are available in ASCII format on a floppy disk. This dataset allows testing of crop growth and development models, biomass production models, and other long-term modelling efforts. It is anticipated that this set will be of greatest value to the plant science community.

*KSC VALIDATED DATABASE:*

In special cases, online access, via internet, to the KSC validated dataset will be made available to institutions which have a specific programmatic requirement for high resolution (5 minute) environmental and physiological response datasets. Access to the KSC validated database is subject to approval and limitations implicit in KSC computer security policies.

Requests for access to the KSC validated database, including the objectives of the research, need for access, and the name, address and telephone number of the principle investigator should be made to:

NASA/CELSS
Mail Code MD-RES
Kennedy Space Center, FL 32899

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This KSC database is being made available to the scientific research community to facilitate the development of crop development models, to test monitoring and control strategies, and to identify environmental limitations in crop production systems. The KSC validated dataset consists of 17 parameters necessary to maintain bioregenerative life support functions: water purification, $CO_2$ removal, $O_2$ production, and biomass production. The data are available on disk as either a DATABASE SUBSET (one week of 5-minute data) or DATABASE SUMMARY (daily averages of parameters). Online access to the VALIDATED DATABASE will be made available to institutions with specific programmatic requirements. Availability and access to the KSC validated database are subject to approval and limitations implicit in KSC computer security policies.

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